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Heritability of root characteristics affecting mineral uptake in tall fescue

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Abstract

Modification of plant roots can potentially increase the area of adaptation of tall fescue (*Festuca arundinacea* Schreb.). Limited information is available on the heritability of root diameter and root volume in tall fescue. A greenhouse experiment was conducted with 50 random 'Kentucky 31' (Ky-31) tall fescue parents and their progeny grown in aerated nutrient solution during four separate time intervals. Measurements of root volume, root diameter, shoot Mg concentration, and shoot K/(Mg + Ca) ratio were made six weeks after clonal material was transplanted in nutrient solution. Heritability estimates for root volume, root diameter, shoot Mg concentration, and shoot K/(Mg + Ca) ratios were determined. Broad sense heritabilities were 0.60, 0.65, 0.32, and 0.58 for root volume, root diameter, Mg concentration, and K/(Mg + Ca) ratios, respectively. Narrow sense heritabilities were 0.41, 0.18, 0.19, and 0.58.

Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is an important forage crop in the temperate zone of much of the world. Yield potential and stand persistence are reduced, however, due to compaction layers found in many soils, such as the Coastal Plain soils of the southeastern United States. Compaction layer restrict root development and prevent root growth into available moisture and nutrients in the subsoil (Elkins *et al.*, 1977). The potential exists to overcome these inherent limitations and extend the area of adaptation through plant breeding.

The response of tall fescue with differing root morphology to soil compaction and water stress was described by Williams *et al.* (1983). Tall fescue plants with large diameter roots (LDR) were thought to penetrate the compacted layers and access subsoil water. Large diameter roots, compared with small diameter roots (SDR), were associated with increased tolerance to plant parasitic nematodes in the field.

Considerable research has been directed toward selecting tall fescue genotypes that accumulate adequate Mg to prevent hypomagnesemic tetany in cattle (*Bos taurus*). Evidence indicates variation in mineral accumulation in tall fescue is under genetic control and heritability (h^2) is high (Buckner *et al.*, 1981; Nguyen and Sleper, 1981; Sleper *et al.*, 1980). Mineral accumulation, including magnesium uptake, has been related to tall fescue root diameter in studies involving four genotypes (Edwards and Pederson, 1987; Pedersen *et al.*, 1987; Torbert *et al.*, 1985). Genotypes with LDR exhibited lower Mg accumulation than SDR genotypes, indicating that selection for LDR could affect the tetany potential of tall fescue.

In cereal crops, root morphological traits are under genetic control (Hurd, 1976). Differences in rice (*Oryza sativa* L.) root characteristics are related to drought resistance and recovery, and are highly heritable (Ekanyake *et al.*, 1985). Root volume and dry weight in barley (*Hordeum vulgare* L.) 'reflect their capacity to absorb nutrients from well-stirred or flowing solutions' (Hackett, 1969).

Root morphology has an influential role in the persistence and adaptability of tall fescue, and its magnesium tetany potential for cattle. However, neither the inheritance of root morphology traits nor an estimate of their variability within a representative population has been determined. Thus, the objectives of this experiment were: 1) to characterize the variation in root diameter and root volume and to provide heritability estimates for these characters in 'Kentucky 31' (Ky-31) tall fescue, and 2) to describe the relationships between root diameter and volume and shoot Mg concentration of Ky-31 tall fescue.

Materials and methods

Fifty random Ky-31 tall fescue parents and three open pollinated progeny from each parent (free of *Acremonium coenophialum* Morgan-Jones and Gams) were maintained in field nurseries. Ramets of each were brought to the greenhouse and used as a source of material in this greenhouse study. Four similar sized propagules (clonal replicates) were selected from each ramet, all tillers and root tissue were removed, and all leaf tissue except approximately 10 mm of the bottom leaf and its sheath were removed.

The propagules were placed in a 12-L tank containing a nutrient solution with the following composition: 0.25 m*M* KCl, 0.25 m*M* KH_2PO_4, 0.25 m*M* NH_4NO_3, 0.5 m*M* $CaCl_2$, 180 μM FeDTPA (diethylene triamine pentaacetic acid), 46 μM B, 9 μM Mn, 0.8 μM Zn, 0.3 μM Cu, and 0.05 μM Mo. Magnesium concentration was maintained at 200 μM. Concentrations were maintained by the addition of tap water and nutrients as required. Solution pH was maintained at 5.6 and 5.8 by the addition of HCl or NaOH. All tanks were vigorously aerated and nutrient solutions were changed one to two times during the course of the experiment. Greenhouse temperature ranged from 24 ± 5°C.

Plants were harvested at six weeks and divided into shoots (leaf blades, leaf sheaths, and stems) and roots. Root volume (mm^3) was determined by measuring the volume of water displaced by the plant root system. Root diameter measurements were made on the three longest primary roots resulting from outgrowth of the propagule. Roots were measured 25 mm behind the root apex using a light microscope and a scaled eyepiece. Roots removed were maintained in a petri dish with moist filter paper and root diameter was determined within 4 h of removal. Shoots were oven dried at 49°C, and stored for Mg concentration determination. Concentrations of Mg, Ca, and K in the shoots were determined by inductively coupled argon plasma spectrophotometry.

Parents and each of their three progeny were grown in separate time intervals (environments) in the greenhouse. In each environment, the experimental design was a randomized complete block with four replications. Means and variances were computed for each trait measured. Analysis of variance was run on the parents and on the progeny grown in three environments. Heritability estimates and their 90% confidence intervals were calculated from the mean squares using the method outlined by Knapp *et al.* (1985).

Results and discussion

Genotype effects were significant for root volume, root diameter, Mg, and the K/(Mg + Ca) ratio in the 50 parents, but were not significant for root volume and the K/(Mg + Ca) ratio in their progeny (Table 1). The genotype × environment interaction was highly significant for progeny root volume, root diameter, and K/(Mg + Ca).

Means, standard deviations, and the range of values observed for these characters in the parents and their progeny are shown in Table 2. Parent root volumes were generally smaller than progeny root volumes, but a considerable range of values was found in both groups. Root diameters and their standard deviations were similar for both groups. Shoot Mg concentration and shoot K/(Mg + Ca) ratio showed evidence of tetany potential in both groups with a considerable range of values in both the parents and their progeny when grown in nutrient solution.

Broad sense heritability estimates (based on parent mean squares) and their 90% confidence intervals are 0.60 ($0.37 < h^2 < 0.70$) for root volume, 0.65 ($0.45 < h^2 < 0.74$) for root diameter, 0.32 ($0.00 < h^2 < 0.74$) for Mg concentration, and 0.58 ($0.35 < h^2 < 0.69$) for shoot K/(Mg + Ca) ratio. Narrow sense heritability

Table 1. Analysis of variance of root volume, root diameter, Mg and K concentrations of fifty random Kentucky 31 tall fescue plants and their open pollinated progeny

	Source	df	Mean square	Prob F > 0
Parents				
Root volume	Rep	3	5.3530	0.0001
	Genotype	49	0.6648	0.0001
	Error	147	0.2666	
Root diameter	Rep	3	0.1046	0.0004
	Genotype	49	0.0461	0.0001
	Error	147	0.0163	
Mg concentration	Rep	3	203654	0.3702
	Genotype	49	285190	0.0393
	Error	147	1933008	
K/(Mg + Ca)	Rep	3	4.6370	0.0001
	Genotype	49	0.4827	0.0001
	Error	147	0.2008	
Progeny				
Root volume	Environment (E)	2	0.225	0.8672
	Rep (E)	9	1.551	0.0001
	Genotype (G)	49	3.283	0.0130
	G × E	98	1.927	0.0001
	Error	440	0.492	
Root diameter	Environment (E)	2	0.433	0.0861
	Rep (E)	9	0.597	0.0009
	Genotype (G)	49	0.073	0.2389
	G × E	98	0.061	0.0001
	Error	440	0.021	0.0001
Mg concentration	Environment (E)	2	3.82×10^8	0.0986
	Rep (E)	9	1.26×10^8	0.2057
	Genotype (G)	49	1.10×10^8	0.2302
	G × E	98	0.92×10^8	0.4984
	Error	440	0.92×10^8	
K/(Mg + Ca)	Environment (E)	2	62.345	0.0001
	Rep (E)	9	1.614	0.0001
	Genotype (G)	49	2.143	0.0283
	G × E	98	1.357	0.0001
	Error	440	0.306	

$^+$ $P = 0.05$ F > 1.

Table 2. Means and standard deviations of root volume, root diameter, and Mg concentration of fifty random Kentucky 31 plants and their progeny

	Volume (mm^3)	Diameter (mm)	Mg concentration ($mg\ g^{-1}$)	K/(Mg + Ca)
Parents				
Mean	1.51	0.90	1771	4.07
Minimum	0.80	0.71	1168	3.23
Maximum	2.33	1.13	3153	4.85
Standard deviation	0.41	0.11	267	0.35
Progeny				
Mean	2.48	0.85	2674	4.32
Minimum	1.65	0.70	654	3.55
Maximum	4.12	1.03	16990	5.26
Standard deviation	0.52	0.08	3030	0.42

estimates (based on progeny mean squares) and their 90% confidence intervals are 0.41 ($0.14 < h^2 < 0.61$) for root volume, 0.18 ($0.00 < h^2 < 0.44$) for root diameter, 0.19 ($0.00 < h^2 < 0.45$) for Mg concentration, and 0.37 ($0.08 < h^2 < 0.58$) for shoot K/(Mg + Ca) ratio. The broad sense h^2 estimates do not account for environmental effects on the phenotype.

The narrow sense h^2 estimates for root diameter and shoot Mg concentration are low and using their 90% confidence intervals they are not different from zero. Selection for these characteristics in nutrient solution is not feasible. Narrow sense h^2 estimates for root volume and the K/(Mg + Ca) ratio are higher. Population means could be shifted for these two characteristics, but because of the magnitude of the h^2 estimates, progeny testing rather than direct phenotypic selection would be indicated.

Correlation coefficients (r) for root volume, root diameter, shoot Mg concentration, and shoot K/(Mg + Ca) ratio are shown in Table 3. Significant correlations were found for root diameter and root volume in both parents and their progeny. A positive correlation between root volume and shoot Mg concentration was observed in the progeny.

Selection for large root diameter using nutrient solution in the Kentucky 31 tall fescue population is inefficient. In our earlier studies, genetic differences were observed in root diameter of tall fescue (Pedersen *et al.*, 1987; Torbert *et al.*, 1985), but the

Table 3. Phenotypic correlation coefficients among root diameter, root volume, Mg concentration, and K/(Mg + Ca) for Ky-31 parents and progeny

	Volume	Mg	K/(Mg + Ca)
Parents			
Diameter	0.60*	−0.19	0.12
Volume	—	−0.12	0.30
Mg	—	—	−0.13
Progeny			
Diameter	0.28*	0.22	−0.15
Volume	—	0.34*	0.04
Mg	—	—	0.13

* Prob. R > 0 = 0.05.

results were based on observations of only four genotypes previously selected for very large or small roots. Root volume can be effectively selected; however, the value of increased root volume in tall fescue is not known.

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